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### Starting Small in an Unfamiliar Environment

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STARTING SMALL IN AN UNFAMILIAR ENVIRONMENT

James E. Rauch and Joel Watson

May 1999

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DEPARTMENT OF ECONOMICS

STARTING SMALL IN AN UNFAMILIAR ENVIRONMENT

BY

JAMES E. RAUCH

AND

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**DISCUSSION PAPER 96-28R  
MARCH 1999**

## STARTING SMALL IN AN UNFAMILIAR ENVIRONMENT

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Motivated by a characteristic way in which firms in developed countries make their decisions regarding cooperation with potential partners from less developed countries, we design a simple model of a DC firm's search for an LDC partner/supplier and the subsequent relationship between the two parties. Matched firms can "start small" with a trial order or pilot project of variable size in order to gain information about the ability of the LDC firm to successfully carry out a large project. We derive results relating whether and how the parties start small to the characteristics of the large project and to the matching environment. Among other results, we show how risk and search cost are associated with the propensity to start small and we establish a connection between starting small and the expected longevity of successful partnerships. We also address methods of contract enforcement and demonstrate the relationship between starting small and monitoring.

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## **I. Introduction**

Partnerships often begin in a state of uncertainty, where there is some doubt about the prospect of success. In such an environment, the partners may "start small" by first attempting small-scale projects and then, if they are successful, graduating to larger ones. In this way, the parties structure their relationship in order to learn about one another before committing a great deal of resources to the enterprise. When deciding how to interact, partners also consider the chance that they will eventually terminate their relationship. The value of termination depends on how easily other matches can be made and on the information available about prospective new partners.

We design a simple model to explore the interaction between how ongoing relationships are structured and the process by which they are formed. The basic, decision-theoretic analysis combines the problem of investment under uncertainty with the problem of optimal search. An extension of the model incorporates the strategic issue of contract enforcement. We study the relationship between parameters of the matching environment (such as the cost of search) and the extent to which partners start small. We also examine complementarities between various endogenous features of partnerships, including the extent of starting small, longevity of partnerships, and methods of contract enforcement. The main goal of our theoretical exercise is to capture, with the simplest possible model, a variety of realistic features of the formation and structure of long-term relationships. We hope this will encourage empirical research on the dynamic structure of partnerships.

Development of our model was motivated by our desire to understand a characteristic way in which developed country (DC) firms make their decisions regarding cooperation with a potential less developed country (LDC) partner. Egan and Mody (1992) surveyed United States buyers operating in LDCs, including “manufacturers, retailers, importers, buyers’ agents, and joint venture partners” (p. 322), and found that “buyers often begin with small orders, perhaps for a simple product, and let the relationship [with the LDC firm] build gradually” (p. 330). The purpose of the small order is to learn about the capabilities of the LDC firm’s manager and workers to meet the DC firm’s requirements for price, quality, and delivery. Egan and Mody state (p. 326):

Buyers looking for either new sources of supply or joint venture partners search for suppliers who manage their factories efficiently, often regardless of the level of technology those factories currently employ; interviewees commonly felt that new machines could easily be installed so long as workers already had the ability to use them efficiently and absorb training readily. For many buyers, management was the most important factor in defining an ideal supplier....As one buyer phrased it, “I do not invest in plant X but in Mr. Y. It all depends on the people.”

We model the DC firm’s search for an LDC partner/supplier and the subsequent relationship between the two parties. Matched firms can “start small” in our model.

Clearly one is more likely to learn Mr. Y’s true type, as it were, the more the initial order resembles the product(s) that the DC firm ultimately wants to buy in large quantity. Hence the DC firm learns more, the more assistance it provides such as visits to the supplier’s plant by engineers or other technical staff. In our analysis we therefore not only allow the DC firm to choose whether or not to start small but also to choose the intensity with which it starts small.

If the small order is filled to the DC firm's satisfaction, it moves on to a large project in partnership with the LDC firm. In practice this ranges anywhere from a large order and finance for working capital to fulfill it up to a joint venture in building a more modern plant with larger capacity.<sup>1</sup> Clearly starting small involves not only direct cost but also delay relative to doing the large project immediately. It can only be understood as a way of avoiding the loss of a large investment in the event that the LDC firm turns out to be incapable of producing at levels of price, quality, and delivery that yield profit to the DC firm. For this reason we will regard the DC firm's investment as irreversible (a sunk cost) in our analysis.

We show that the intensity with which the DC firm starts small is increasing in the probability that the large project will be successful, increasing in the profitability of the large project, and decreasing in the investment the large project requires. We also show that the more risky is the large project, the more likely is the DC firm to start small.

The risk of a failed partnership is not the only reason a DC firm might want to start small. The high cost of finding another partner might be a factor as well: otherwise, if the odds for success do not look good enough, why not just find another partner? Hence we speak of an "unfamiliar" rather than an "uncertain" environment: it is not just the riskiness of investment in LDC partners but also the high cost of search in LDCs that may favor starting small. The cost of search is therefore a key parameter in our analysis, and we confirm that starting small is more likely when search costs are high.

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<sup>1</sup>We assume that only one large project is available and therefore do not attempt to explain the choice between different types of large project. To some extent this choice is determined by the DC firm's characteristics, e.g., whether it is a retailer or a manufacturer.

Since in our model uncertainty of the DC firm regarding its investment is resolved in an ongoing relationship with its partner, a new supplier (e.g., from another LDC) is placed at a disadvantage relative to the existing supplier even if the initial investment of the DC firm has been fully depreciated and must be renewed. In other words, the fact that the DC firm does not know the “type” of the new supplier but has learned that its current supplier is the “good” type (otherwise it would have found another one) makes it more difficult for the former to break into the DC market. On the basis of their aforementioned survey, Egan and Mody (1992, p. 329) report that “U.S. buyers prefer to stay with suppliers they know....Buyers commonly report taking on new suppliers only when they foresee increased sales beyond current suppliers’ capacity or when existing suppliers cannot meet changing quality or price requirements....the number of ‘windows of opportunity’ for new supplier firms may be limited.” We derive results on the persistence of relationships between DC firms and their partners. Given certain restrictions we are able to show that, conditional on a successful large project, the expected longevity of a partnership that started small is at least as great as the expected longevity of a partnership that started big.

In addition to the problem of finding a high-quality LDC firm with which to establish a partnership, DC firms may be concerned with motivating LDC partners to perform over time. In other words, contracts specifying effort on the part of the LDC firms must be enforced. As Egan and Mody (1992, p. 326) put it, DC firms find it important that LDC partners “do what they say they will do.”<sup>2</sup> Enforcement is particularly challenging in the setting of DC-LDC partnerships,

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<sup>2</sup>Egan and Mody cite Vernon-Wortzel, Wortzel, and Deng (1988) in explaining that “some suppliers, especially those trying to penetrate a new market, promise quantities, delivery dates, or prices which they cannot achieve, and then are surprised at the buyer’s angry reaction.”



since international and LDC legal institutions are not as powerful or developed as those within DCs.

An extension of our model allows us to address the roles of three common enforcement institutions: direct enforcement (monitoring), self-enforcement, and community enforcement. We highlight the role of monitoring, which is especially important and visible in practice. For example, Rhee et al. (1984, p. 62) state of Korean exporters of manufactures that, “Because of the activities of foreign buyers in supervising and checking export shipments, the exporting firms had a strong motive to implement effective methods of quality control.”<sup>3</sup> We demonstrate theoretically how the level of monitoring depends on the LDC firms’ prospects for establishing relationships with new DC partners. These prospects are influenced by matching friction, the extent of community enforcement, and the degree of caution exercised by DC firms at the beginning of relationships. We emphasize the inverse relation between starting small and monitoring.

Our model is related to two strands of the literature. The main, decision-theoretic, component of our analysis is most clearly related to the literature on irreversible investment under uncertainty (e.g., Dixit and Pindyck 1994). Unlike this literature, our analysis embeds the investing firm’s decision within a search problem, and information is revealed by “starting small” rather than by the passage of time.<sup>4</sup> Closer in spirit to our model is Horstmann and Markusen (1996), who analyze the choice by a multinational firm seeking to enter a new (foreign) market

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<sup>3</sup>Egan and Mody (1992) further point out the value of frequent contact and reliable communication technologies.

<sup>4</sup>Dixit and Pindyck (1995, p. 111) provide a numerical example where a firm can invest in R&D to reveal information rather than rely on the passage of time.

between direct investment and contracting with a local sales agent. Information gained from the agency contract is useful in the decision whether to pursue direct investment, hence the agency contract is analogous to “starting small” (though unlike starting small in that it may be desirable to extend it indefinitely). Again, the firm’s decision is not embedded within a search problem in that it cannot search over potential agents. Within the search literature, the closest model appears to be that of Jovanovic (1979) since he allows the searching worker to learn about the quality of his match with a firm over time rather than having to decide immediately whether to match for life or look for another firm. Again information is revealed only by the passage of time, so *a fortiori* the worker cannot vary the intensity of the “investment” in learning he is making (by staying with the present firm) at any point in time.<sup>5</sup>

To allow our model to handle these complications we simplify greatly (relative to, say, Dixit and Pyndyck 1994) the modeling of time (discrete rather than continuous) and of uncertainty (the outcome of the large project is permitted to take only two values). We feel that little is lost thereby for our purposes because we do not want to develop decision-making guidelines such as hurdle rates or optimal stopping rules.

The second strand of the literature relevant for our theoretical exercise is that which analyzes incentives for ongoing cooperation when severance leads to random rematching. Examples include Ramey and Watson's (1996) model of contracting and ownership, Datta (1996),

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<sup>5</sup>Our model identifies starting small as a response to uncertainty. The literature contains some complementary work in which starting small arises due to asymmetric information. For example, Watson (1996) studies a model of partnerships in which agents are uncertain about each others’ incentives. He shows that it is optimal to start small and gradually raise the stakes in such an environment. In the present context, possibilities for opportunistic behavior on the part of an LDC partner are greatly reduced by the monitoring to which it is routinely subjected by the DC firm.

and Ghosh and Ray (1996). Also worth noting is Watson's (1999a,b) analysis of starting small in settings of incomplete information. We discuss these and other papers below.

The next section of this paper presents the assumptions and notation of our model and establishes the existence of a unique solution. Sections III, IV, and V derive our results. Of these, the latter two sections consider extensions of the basic model to address search during a productive relationship and contract enforcement, respectively. Conclusions and suggestions for further research are presented in Section VI. The Appendix contains all of the formal proofs.

## II. The model

### A. Assumptions and notation

We can outline the problem of the DC firm as follows. It searches in discrete time over a large (infinite) pool of LDC firms for a partner in a large project. In a given period it locates a potential partner at cost  $\gamma$ , with whom it can interact in succeeding periods. The DC firm then has three choices:

- (1) Invest in the large project immediately (*Big*);
- (2) Run a small pilot project that may provide information on the chance of success of the large project (*Learn*); and
- (3) Reject the partner and return to searching (*Out*).

We assume that the small project may be undertaken with intensity  $r \in [0,1]$ , at cost  $c(r)$ . With probability  $r$  the nature (success or failure) of the large project is revealed at the end of the period,

and with probability  $1 - r$  no information regarding the large project is revealed. For simplicity the small project is assumed to have no yield other than this information.<sup>6</sup>

To describe the problem formally we introduce the following notation. Each partner drawn from the pool is described by a tuple  $(\pi, p, I, c)$ , with the following interpretation. The value  $\pi$  is the total discounted sum of DC firm profit if the large project is successful; that is, successful large project pays  $(1 - \delta)\pi$  each period, where  $\delta$  is the firm's discount rate. If the large project fails, profit is zero. The parameter  $p$  is the DC firm's *a priori* assessment of the probability that the large project will be successful.  $I$  denotes the amount the DC firm must invest in the large project. Finally,  $c$  is a strictly convex function of  $r$ , with  $c'(0) = 0$  and  $\lim_{r \rightarrow 1} c'(r) = \infty$ . The pool of potential partners is defined by a distribution over such tuples. The following variables are endogenously determined:

$w$  denotes the value, inclusive of search cost, of selecting a partner from the pool at random.

$u$  denotes the expected value associated with a given partner.

$u^O$  denotes the expected value of rejecting the current partner.

$u^B$  denotes the expected value of investing in the large project with the current partner.

$u^L$  denotes the expected value of starting small with the current partner.

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<sup>6</sup>We could relax this assumption by, for example, allowing the investment in the small project to reduce the investment required for the large project on a less than one-for-one basis without qualitatively changing any of our results.

Figure 1 shows the sequence and timing of the DC firm's decisions.<sup>7</sup>

### B. Solution

To solve our model we start by characterizing the optimal course of action for a generic partner selected from the pool, with  $w$  fixed. We then complete the solution by endogenizing  $w$ .

Given our description of the DC firm's problem, our notation, and Figure 1, it is clear that  $u = \max \{u^B, u^L, u^O\}$ , where

$$u^O = \delta w,$$

$$u^B = p\pi + (1 - p)\delta w - I, \text{ and}$$

$$u^L = \max_r [r(p\delta(\pi - I) + (1 - p)\delta w) + (1 - r)\delta u^L - c(r)].$$

Note that  $u$  depends on  $(\pi, p, I, c)$  and the value  $w$ .

In section III below we establish that there exists a set of potential partners of nonzero measure for which it is optimal to choose *Learn* over *Big* and *Out*. For those partners for which *Learn* is best, we can at this point determine the optimal intensity  $r$  of the effort made to learn whether or not the large project will succeed. Fixing  $(\pi, p, I, c)$ , let

$A \equiv p\delta(\pi - I) + (1 - p)\delta w$ . The equation

$$u^L = \max_r [rA + (1 - r)\delta u^L - c(r)]$$

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<sup>7</sup> A comment is in order regarding why the outcome “No news” leads to the choice “*Learn* (again)”: if the small project yields no information in period  $t$ , the DC firm is in the same situation in period  $t+1$  and therefore makes the same choice: to start small.

defines  $u^L$  and  $r^*$ , the optimal choice of  $r$ . The assumptions on  $c$  guarantee that the maximum exists and is characterized by the first-order condition, which is  $A - \delta u^L - c'(r^*) = 0$ . We also have the identity  $u^L = r^*A + (1-r^*)\delta u^L - c(r^*)$ , which simplifies to

$$u^L = \frac{r^*A - c(r^*)}{1 - (1-r^*)\delta}.$$

Substituting this into the first-order condition yields

$$c'(r^*) = \frac{(1-\delta)A + \delta c(r^*)}{1 - (1-r^*)\delta}. \quad (1)$$

To see that the solution exists and is unique, write equation (1) as  $c'(r)[1 - (1-r)\delta] - \delta c(r) = (1-\delta)A$ , and note that the derivative of the left-hand side is  $c''(r)[1 - (1-r)\delta] > 0$ . At  $r = 0$  the left-hand side is nonpositive and, since  $c(1)$  is finite, the left-hand side is arbitrarily large as  $r$  approaches one. We thus have:

**Proposition 1:** *Within the set of partners for which starting small is optimal,  $r^*$  increases with  $\pi$ ,  $p$ , and  $w$  and decreases with  $I$ .*

The intuition behind Proposition 1 is that the cost of learning nothing is further delay in pursuing the opportunity at hand. The more valuable the opportunity, the more costly the delay, and hence the more effort it is worth spending to learn enough to decide now rather than later.

To complete the solution of our model we need to show that there exists a (unique)  $w^*$  that solves  $w^* = Eu(\pi, p, I, c; w^*) - \gamma$ , where the expectation is taken over  $(\pi, p, I, c)$  according to the distribution of the pool of potential partners.

**Proposition 2:** *Fix a distribution over  $(\pi, p, I, c)$  such that  $p\pi > I$  with positive probability. There exists a number  $\underline{\gamma} > 0$  such that for every  $\gamma > \underline{\gamma}$  no search takes place and for  $\gamma < \underline{\gamma}$  there is a unique  $w^* = Eu(\cdot; w^*) - \gamma$ .*

### III. Basic Results: Risk, Search Cost, and Starting Small

In order to establish the results below it is necessary to start with computations of how the values of the choices *Big*, *Learn*, and *Out* vary with the characteristics  $(\pi, p, I)$  of the potential partner in hand. For all  $(\pi, p, I, c)$  for which  $\pi - I > w$ , we have

$$\frac{\partial u^O}{\partial p} = 0 < \frac{\partial u^L}{\partial p} = \frac{r^* \delta (\pi - I - w)}{1 - (1 - r^*) \delta} < \frac{\partial u^B}{\partial p} = \pi - \delta w; \quad (2)$$

$$\frac{\partial u^O}{\partial \pi} = 0 < \frac{\partial u^L}{\partial \pi} = \frac{r^* p \delta}{1 - (1 - r^*) \delta} < \frac{\partial u^B}{\partial \pi} = p; \quad (3)$$

and

$$\frac{\partial u^O}{\partial I} = 0 > \frac{\partial u^L}{\partial I} = \frac{-r^* p \delta}{1 - (1 - r^*) \delta} > \frac{\partial u^B}{\partial I} = -1. \quad (4)$$

In the event that  $\pi - I < w$ , the optimal decision is obviously *Out*.<sup>8</sup>

From inequalities (2) - (4) and Figure 2 we can see how  $w^*$  changes in response to (static) changes in the pool of potential partners. If more probability is put on higher  $\pi$  in the pool of potential partners (e.g., a new distribution over  $\pi$  that first-order stochastically dominates the old one), then  $w^*$  weakly increases. To see this, note that  $\partial u / \partial \pi \geq 0$  by inequalities (2) and hence  $Eu(\cdot; w)$  weakly increases for all  $w$ , causing  $w^*$  to weakly increase by Figure 2. By the same logic, if more probability is put on higher  $p$  or lower  $I$  in the pool of potential partners,  $w^*$  weakly increases since  $\partial u / \partial p \geq 0$  and  $\partial u / \partial I \leq 0$  by inequalities (3) and (4), respectively.<sup>9</sup>

Fixing a pool (distribution) of potential partners, let us next consider the choice between *Big*, *Learn*, and *Out* for a partner drawn from the pool. Figure 3 demonstrates the relationship between  $u^B$ ,  $u^L$ , and  $u^O$  for various  $(\pi, p, I, c)$ . In Figure 3a, these are graphed as functions of  $\pi$ , with the other parameters fixed. Figures 3b and 3c graph these as functions of  $p$  and  $I$ , respectively. Inequalities (2) - (4) establish the relative slopes of the functions. Note that  $u^B$  and  $u^O$  are linear and  $u^L$  is convex in each of  $\pi$ ,  $p$ , and  $I$ .<sup>10</sup>

We can see that starting small is favored for partners with intermediate values of  $\pi$ ,  $p$ , and  $I$  (e.g.,  $\pi$  between  $\pi'$  and  $\pi''$  in Figure 3a): if the values of  $\pi$  and  $p$  are too low and the value of  $I$  is too high, it is optimal to return to the pool; and if the values of  $\pi$  and  $p$  are too high and the

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<sup>8</sup>The condition  $\pi - I > w$  also insures that it is not optimal to search for another (better) partner while a successful large project is in place, implemented and producing profit. In subsection B we consider the case when new partners can be located without costly search.

<sup>9</sup>Our argument is obvious if  $\pi$ ,  $p$ , and  $I$  are independently distributed. With the appropriate definition of first-order stochastic dominance, the result extends to correlated distributions.

<sup>10</sup>Convexity of  $u^L$  follows directly from the comparative statics of  $r^*$  and inequalities (2) - (4).



value of  $I$  is too low it is optimal to start the large project immediately. We need to show that values for which starting small is optimal do in fact exist.

**Proposition 3:** *Take any distribution  $\sigma$  over  $(\pi, p, I, c)$ , defining the pool of potential partners. There is another distribution  $\sigma'$  and a number  $\bar{a} \in (0, 1)$  such that for all  $a \in (0, \bar{a})$ , the population defined by  $\hat{\sigma}_a \equiv a\sigma' + (1-a)\sigma$  has the property that it is optimal to start small with a positive mass of potential partners.*

The basic idea of the proof is simple. Suppose  $w^*$  is the value associated with population distribution  $\sigma$ . Recalling the definition of  $A$ , for  $\pi - I > w^*$  and  $p > 0$  we have  $A(w^*) = p\delta(\pi - I) + (1 - p)\delta w^* > u^O(w^*) = \delta w^*$ . We can also find a positive  $p$  such that  $A(w^*) > u^B(w^*) = p\pi + (1 - p)\delta w^* - I$ , which holds for  $p < I/[(1-\delta)\pi + \delta I]$ . Recalling that  $u^L = [r^*A - c(r^*)]/[1 - (1-r^*)\delta]$ , we can make  $u^L(w^*)$  arbitrarily close to  $A(w^*)$  by choosing  $c(r)$  appropriately (i.e., so that  $r^*$  close to one is chosen at very low cost). We have thus shown that we can create a partner for which *Learn* is preferred to *Big* and *Out*. We then let  $\sigma'$  be the distribution that puts all mass on that partner. The final step addresses that  $w^*$  changes because the pool of potential partners is changing.

We now want to establish that the higher the risk of a potential partnership, the more likely is the DC firm to start small. Clearly a more risky partnership is one with lower probability of success of the large project and a higher required investment, keeping the expected return to the large project constant. We will interpret the latter clause to mean increasing  $\pi$  so that  $u^B$  remains constant when  $p$  falls and  $I$  increases. We can then prove the following proposition, establishing that a more risky partner favors *Learn* over *Big*:

**Proposition 4:** *Given a fixed pool, consider two potential partners described by  $(\pi, p, I, c)$  and  $(\pi', p', I', c)$  where  $p' < p$ ,  $I' > I$ , and  $u^{B'} = u^B$  (implying  $\pi' > \pi$ ). In this case  $u^{L'} > u^L$ .*

It follows that having the option to start small increases the value of a more risky pool to the DC firm, in a sense we will now make precise. Fix a common cost function  $c(r)$  in the population and take a distribution  $\sigma$  over the characteristics  $(\pi, p, I)$  of potential partners. Consider a class  $\Gamma$  of potential partners parameterized by a real number  $\alpha$ . Each partner in this class is described by  $(\pi(\alpha), p(\alpha), I(\alpha))$  for some  $\alpha$ . Suppose that partners in this class have the same value of starting big, given the endogenous  $w^*$ . That is,  $p(\alpha)\pi(\alpha) + [(1-p(\alpha))\delta w - I(\alpha)]$  is constant in  $\alpha$ . Further suppose that  $\pi(\alpha)$  is increasing in  $\alpha$ ,  $p(\alpha)$  is decreasing in  $\alpha$ , and  $I(\alpha)$  is increasing in  $\alpha$ . Then  $\alpha$  measures the risk of a potential partner in this class, relative to the value of starting big.

Now consider a distribution  $\hat{\sigma}$  over potential partners that is identical to  $\sigma$  except that the distribution over class  $\Gamma$  first order stochastically dominates in  $\alpha$  the distribution implied by  $\sigma$ . In other words,  $\sigma$  and  $\hat{\sigma}$  assign the same probability weights to partners outside of class  $\Gamma$ ; in class  $\Gamma$ ,  $\hat{\sigma}$  puts higher probability on larger  $\alpha$  (riskier partners). Let  $\hat{w}^*$  be the endogenous value of selecting a partner from the pool under distribution  $\hat{\sigma}$ . Then  $\hat{w}^* \geq w^*$ , since  $u^L$  is increasing in  $\alpha$  by Proposition 4 and hence  $Eu(\cdot; w)$  is weakly greater under  $\hat{\sigma}$  than under  $\sigma$ , for all  $w$ .

Next we establish that the DC firm is more likely to start small in an environment that is more unfamiliar in the sense that search costs are higher.

**Proposition 5:** *Given a fixed pool, if the cost of search  $\gamma$  increases then the mass of potential partners for whom starting small is optimal weakly increases.*

To see the intuition behind this result, observe that a higher search cost implies a smaller value of  $w^*$ . Also note that part of the cost of waiting to learn about an LDC firm's type is the

delay in returning to search in the event that the project is unsuccessful. This cost of delay is proportional to  $w^*$ . Thus, when the outside opportunity for DC firms is reduced, it lowers the value of starting big, relative to the value of starting small.

#### **IV. Persistence of Partnerships With Random Arrival of New Opportunities**

Once a DC firm enters into a partnership with an LDC supplier it may gain access to an information network composed of firms engaged in similar partnerships. Egan and Mody (1992, p. 329) report that “virtually all buyers first seek information within their own network. This network is a tight system of product-specific buyers and suppliers of both finished goods and components.” Through this network, new potential LDC suppliers may come to the DC firm’s attention without the latter having to engage in costly search.

As discussed in the Introduction, exogenous market changes may cause “windows of opportunity” to open that allow new LDC partners to replace existing ones. We model this simply by assuming that large projects require the investment  $I$  every  $n$  periods, rather than assuming that  $I$  lasts indefinitely as before, and that DC firms cannot change partners except when  $I$  needs to be renewed, so that a “window of opportunity” arises every  $n$  periods. We thus append our model so that if  $t$  is the period in which the most recent investment was made, with probability  $q$  the DC firm obtains information about another potential partner between periods  $t+1$  and  $t+n$ , on which it can act in period  $t+n$ . In the event that information is obtained, the DC firm can choose whether to continue with the current partner (discarding the new opportunity) or abandon the current project and join with the new partner. If no information is obtained, the DC firm obviously stays with the current partner. Assume that starting small is not an option with the new

partner.<sup>11</sup> Thus, the relevant information about the new partner is summarized by some profile  $(\pi', p', I')$ .<sup>12</sup> Notice that the DC firm does not know whether the new large project will be successful when deciding whether to take the opportunity. If it abandons the current project in favor of a new one that is unsuccessful, then the DC firm must return to the pool to search for yet another partner (with which it has the option to start small).

Let  $v(\pi, I)$  be the value of running the big project, starting from an investment period, conditional on the project known to be successful. It can easily be shown that the value of investing and running the project for  $n$  periods is  $(\pi - I)(1 - \delta^n)$ . We can then see that  $v(\pi, I)$  is implicitly defined by the equation

$$\begin{aligned} v(\pi, I) = & (\pi - I)(1 - \delta^n) + \delta^n(1 - q)v(\pi, I) \\ & + \delta^n q E_{(\pi', p', I')} [\max[v(\pi, I), p' v(\pi', I') + (1 - p')\delta w]], \end{aligned} \quad (5)$$

where the expectation is taken over the pool of potential partners. Note that  $w$  is a parameter in the function  $v$ ; therefore, we will use the notation  $v(\pi, I; w)$ .

To complete the model, we need to show that  $v$  is well-defined. Then we must show that the endogenously defined  $w$  exists as well. Using standard techniques in recursive analysis (see, for example, Stokey and Lucas (1989)) we find that the functional mapping defined by equation (5) is a contraction. This implies that the (fixed point) function  $v$  uniquely exists. We also

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<sup>11</sup>The option of starting small can be included, but only at the cost of less transparent analysis.

<sup>12</sup>In order to keep  $\pi$  as the value of the big project (after the initial investment  $I$ ), we define  $\theta(1 - \delta)$  as the return per period. We then have  $\pi = \theta - \delta^n I / (1 - \delta^n)$ . The net value of the successful project is  $\pi - I$ , as before, and potential partners are defined by  $(\pi, p, I, c)$  as before. (The per period return  $\theta$  is defined by  $\pi$  and  $I$ .)

establish three properties of this value function. First,  $v$  is continuous in  $(\pi, I, w)$ . Second,  $v$  is increasing in  $\pi$ - $I$ . Third,  $v$  is increasing in  $w$  and for  $w' > w$ ,  $[v(\pi, I; w') - v(\pi, I; w)] < \delta^n(w' - w)$ . That is, as a function of  $w$ ,  $v$  has a non-negative slope that is bounded away from one.

In this expanded model, the expected values of choosing *Big*, *Learn*, and *Out* with a partner discovered by search are defined as in the original model. We have that  $u^B = pv(\pi, I; w) + (1 - p)(\delta w - I)$ ,  $u^L = [r^*B - c(r^*)]/[1 - (1 - r^*)\delta]$ , and  $u^O = \delta w$ , where  $B \equiv p\delta v(\pi, I; w) + (1 - p)\delta w$ . The proof that the endogenous  $w$  exists then follows the proof of Proposition 2 in section II.B above.

Two interesting results arise in our expanded model. First, uncertainty about a new partner's success inhibits the decision-maker from abandoning a current partner, even when the value of the new partnership potentially exceeds the value of the current one. To see this, note that when information surfaces about a new partner  $(\pi', p', I')$ , the current partner is dropped only if  $v(\pi, I) < p'v(\pi', I') + (1 - p')\delta w$ . It must be that, for the current partner,  $v(\pi, I) > \delta w$ . Suppose (realistically) that the probabilities of success for those in the pool of prospective partners are uniformly bounded away from one. Then there is a positive number  $g$  such that the new partner is chosen only if  $v(\pi', I') > v(\pi, I) + g$ .

The second result concerns the relationship between whether one started small in realizing a successful large project and the longevity of the partnership. Consider a distribution over potential partners, with  $w$  endogenously determined. Take a collection of partners from those in the pool satisfying two properties. First, these partners are parameterized by  $\alpha$ , with  $0 < \alpha < 1$ . That is, a partner from this set is given by  $(\pi(\alpha), p(\alpha), I(\alpha))$ . Second, the value of starting big is the same for each of these partners. Suppose that  $\pi(\alpha)$  is increasing,  $p(\alpha)$  is decreasing, and  $I(\alpha)$  is

increasing. Then  $\alpha$  is a measure of risk relative to the value of starting big. A similar idea was explored briefly earlier, where we saw that a higher  $\alpha$  raises  $u^L$ . It follows that successful large projects with higher  $\alpha$  are more likely to have been started small, so that starting small selects positively for  $\pi - I$ , and thus for  $v(\pi, I)$ . The DC firm is therefore less likely to abandon a partner with which it started small for a new one. These facts imply that, for partners that vary by risk relative to the value of starting big, whether a partnership is started small is positively correlated with the longevity of a successful match.<sup>13</sup> More formally, we can prove the following proposition:

**Proposition 6:** *For a fixed population, take any collection of partners parameterized by  $\alpha$  as described above. Let  $X$  and  $Y$  be any two partners from this set, and suppose that it is optimal to choose Learn with  $X$  and choose Big with  $Y$ . Conditional on a successful large project, the expected longevity of a partnership with  $X$  is at least as great as the expected longevity of a partnership with  $Y$ .*

## V. Strategic Consideration: Contract Enforcement

To this point, we have taken a simple decision-theoretic approach to analyzing partnership dynamics. Now we shall address some strategic issues by extending our model to incorporate an incentive problem. Suppose a successful large project requires ongoing effort on the part of the LDC firm. In order to produce, the firms must find a way to enforce a contract specifying that the LDC firm will exert the appropriate amount of effort over time. We explore how the firms deal

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<sup>13</sup>While it is tempting to attribute this greater expected longevity of partnerships that started small to greater relationship-specific investment than in partnerships that started big, this is only true insofar as the investment  $c(r)$  in information is associated with a riskier project.

with the moral hazard problem and, in particular, how the method of contract enforcement relates to whether the firms start small in their relationship.

There are several enforcement institutions to consider. Under *self-enforcement*, the firms agree that continued cooperation is contingent on effort by the LDC firm in the past. With this expectation, the LDC firm may be motivated to expend effort, foregoing short-term gains from shirking, in order to preserve the valuable relationship. A *community enforcement* scheme features the same trade-off, but it includes punishment by third parties. In this case, news of misbehavior by the LDC firm will be disseminated to other firms (such as its prospective future DC partners) who contribute to the punishment. Finally, *direct external enforcement* refers to a legal institution or commitment technology that enforces contracts written by the LDC and DC partners. For example, increased monitoring of LDC firm activities can reduce discretion and the scope for opportunism.

We shall keep our model simple by adopting the minimal extensions necessary to address contract enforcement. We add to the basic model defined in Section II. Suppose that, once the firms undertake a successful large project, the LDC firm must privately select an effort level each period. Effort in a period can be either High or Low. High effort in a period yields the output  $\pi(1-\delta)$  to the DC firm in the period, as in the basic model. High effort also generates  $b(1-\delta)$  to the LDC firm in each period.<sup>14</sup> On the other hand, low effort generates a private return of  $x$  to the LDC firm in the current period. It also yields a return to the DC firm that we assume is small enough so that the DC firm would never wish to produce under low effort. In addition, low effort

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<sup>14</sup>Assume, for simplicity, that the LDC firm does not make an effort choice when *Learn* is chosen in a period. Further, the LDC firm obtains zero except during production of a successful large project.

destroys the value of continuing the relationship and thus causes the relationship to sever.<sup>15</sup> When the relationship is severed, the DC firm obtains  $w$  in the following period, as in the basic model.

The severance value for the LDC firm, from the start of the next period, is denoted  $z$ .

To understand whether high effort can be enforced, consider the incentives of the LDC firm in a given period during implementation of the large project. If it always expends high effort, the LDC firm obtains the value  $b$ , which is the discounted sum of returns. If it expends low effort, it obtains  $x + \delta z$ . Thus, high effort can be sustained if and only if  $b \geq x + \delta z$ . We call this the *effort constraint*.

The value  $x$  depends on how much the DC firm monitors the LDC firm. By monitoring the LDC firm, the DC firm can reduce the gains from behaving opportunistically. Thus, monitoring is a form of direct contract enforcement.<sup>16</sup> We suppose monitoring is done by a *sentry*, who is employed by the DC firm. To keep the analysis simple, we assume the sentry's compensation is fixed and does not depend on the amount of time he spends monitoring the LDC firm. Under threat of punishment by the DC firm, the sentry monitors just enough to ensure high effort.<sup>17</sup> Letting  $\mu$  denote the resources spent monitoring the LDC firm in a given period, we

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<sup>15</sup>Low effort may destroy physical capital and/or the firms' trust in one another.

<sup>16</sup>In practice, monitoring also helps the LDC firm obtain information about the trustworthiness of the DC firm. We have modeled the information role only through the starting small decision. See Watson (1999a,b) for an analysis of learning in an incomplete information environment.

<sup>17</sup>Here we are abstracting away from studying any trade-off between monitoring and the sentry's compensation. This allows us to avoid studying how monitoring costs feedback to the returns of the DC firm. A more complete model of contracting and the sentry's incentives does not alter the qualitative results on monitoring and starting small which we address in this section. The broader approach leads to some messy technical issues regarding existence of equilibrium, which we are able to avoid by taking the more abstract route.



write  $x(\mu)$  as the function relating the short-term gain of low effort to the level of monitoring. We assume  $x$  is a strictly decreasing function of  $\mu$ , with  $x(0) > b$  and  $x(\mu) < b(1-\delta)$  for some  $\mu$ . The sentry selects the smallest  $\mu$  that satisfies the effort constraint:  $x(\mu) + \delta z = b$ . Rearranging this expression and inverting  $x$  reveals the required monitoring level in each period to be  $m(z) \equiv x^{-1}(b-\delta z)$ . Observe that  $m$  is increasing. We assume this function is the same for all DC-LDC relationships.

The DC firm's problem and the determination of  $w^*$  is exactly as analyzed in Section II. To complete the analysis in this expanded setting, we must describe the endogenous parameter  $z$  and determine its value in equilibrium. This requires us to be more explicit about the prospects for a given LDC firm, in particular one that is not matched with a DC partner. We suppose that the pool of LDC firms is divided between those who are currently matched and those waiting to make a match. An LDC firm obtains zero when unmatched. If a relationship between an LDC and a DC firm is terminated in a period, the LDC firm returns to the unmatched pool in the following period and awaits another match. After separation, the DC firm behaves as analyzed in Section II.

We make the following assumptions concerning LDC characteristics. First, the characteristics  $(\pi, p, I, c)$  of an LDC firm are independent of the DC firm with which it is matched. Second, whether the large project is successful is redrawn with each new DC firm faced. Under these assumptions, different DC firms would behave the same way toward an individual LDC firm.<sup>18</sup> Finally, we assume that an unmatched LDC firm is matched with a DC suitor in a given

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<sup>18</sup>This could be relaxed somewhat, but some correlation between characteristics when matched with different firms is required for our results.

period with probability  $s$ . This number reflects the state of the matching market (frictions and relative numbers of DC and LDC firms) as well as the extent of community enforcement, as discussed below.<sup>19</sup>

In our matching environment,  $z$  solves

$$z = s\phi[pb + (1-p)\delta z] + (1-s)\delta z, \quad (6)$$

where  $\phi$  reflects discounting due to the expected time it takes to learn whether the large project is successful in a new relationship. In the case of starting *Big*, where the success of the large project is discovered immediately, we have  $\phi = 1$ . When the DC firm selects *Learn*, we have  $\phi = \delta r^* / [1 - \delta + \delta r^*]$ . Note that, in the case of *Learn* (starting small),  $\phi < 1$  and  $\phi$  is increasing in the intensity of learning,  $r^*$ . Finally, when *Out* is optimal for the DC firm, we have  $\phi = 0$ . We interpret  $1/\phi$  as the *degree* to which a DC firm exercises caution with a partner LDC firm. The first two assumptions described in the previous paragraph imply that  $\phi$  is a function of the LDC firm's fixed characteristics. Note that  $\phi$  is idiosyncratic to an individual LDC firm; thus, the pool of LDC firms may encompass many different values of  $\phi$  (and thus  $z$ ).

The model yields immediate results regarding the method of contract enforcement.

Solving (6) for  $z$ , we have  $z = Fb$ , where

$$F \equiv s\phi p / [1 - \delta + \delta s(1 - \phi(1 - p))].$$

One can easily verify that  $\partial F / \partial \phi > 0$  and  $\partial F / \partial s > 0$ . Coupled with  $m$  increasing, these facts imply the following result.

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<sup>19</sup>To be complete, we should provide conditions under which the matching market is active and the populations stable over time. By including random exogenous separation, this can be done without much difficulty.

**Proposition 7:** *In every DC-LDC relationship, the amount of monitoring,  $\mu$ , is directly related to the LDC matching probability,  $s$ , and inversely related to the degree of caution exercised by the DC firm,  $1/\phi$ .*

The proposition provides a simple basis for understanding how contracts are enforced in our theoretical setting. Note that LDC firms are disciplined by both monitoring and the threat of severance. Monitoring is only needed to the extent that severance is not very costly to an LDC firm. Thus, to determine how much monitoring will take place, we simply ascertain the LDC firm's value of severance.

We wish to emphasize how the value of severance relates to the degree of caution exercised by DC firms, which further implies a relation between monitoring and starting small. To generate intuition for this part of Proposition 7, note that, when an LDC firm's characteristics render it a risky partner, DC firms will prefer to start small with it. But starting small is an exercise of caution, which entails delay ( $\phi < 1$ ). This caution lowers the LDC firm's value of starting a new relationship. As a result, its gains from cheating are reduced, which lowers the amount of monitoring necessary to induce effort.<sup>20</sup>

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<sup>20</sup>Our result is related to the findings of Ghosh and Ray (1996). They demonstrate that starting small may arise under incomplete information and that this helps discipline players in long-term relationships. Watson (1999a,b) provides the most complete study of the dynamics of cooperation under incomplete information. Datta (1996) and Kranton (1996) also discuss how starting small can serve a disciplining role in games. Carmichael and MacLeod (1997) demonstrate how a social convention requiring the exchange of gifts at the beginning of relationships can help sustain cooperation. Our work is distinguished by the breadth of enforcement devices studied, in particular monitoring and difficulty finding a new partner. In addition, we emphasize starting small as a response to joint uncertainty, rather than asymmetric information.

The need for monitoring is also reduced when  $s$  is small. There are two reasons why this may be the case in reality. First, the LDC firm side of the matching market may be very long, meaning there are more LDC firms than DC firms looking for partners. In this case, LDC firms have to wait a substantial amount of time before being matched, if at all. Second, a small value of  $s$  may reflect the use of coordinated community sanctions. If an LDC firm behaves opportunistically, its DC partner disseminates the news to other DC firms who may be prospective new partners for the LDC firm. Under the expectation that the LDC firm will exert low effort in future relationships, other DC firms would be unwilling to initiate a partnership with this firm. As a result,  $s$  decreases for LDC firms that have misbehaved.<sup>21</sup>

In general, community sanctions are likely to be effective when DC firms communicate regularly and share information about the performance of LDC firms. Strong network ties, which are often maintained in reality, can facilitate the required communication. Intermediaries can also play an important role in this regard. Egan and Mody (1992, p. 330) verify the practice of community enforcement and the existence of networks. They write:

Although buyers typically do not tell other buyers of particular deals with suppliers, they often will discuss the suppliers' qualifications, demands, and past performance. Willingness to supply accurate supplier references is a part of the mutual obligations within the industry network.

Our analysis in this section is intended to be quite simplistic, allowing us to generate useful intuition on strategic issues without additional theoretical complexity. As a result, we have left out some features of relationships that are obviously important as well, and we have not touched on several other theoretical issues. For example, it would be instructive to perform a

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<sup>21</sup>Kandori (1992) and Greif (1993), among others, have studied community enforcement.

fuller analysis of the matching process and to consider more sophisticated contracting. In addition, we have not modelled contract negotiation between the LDC and DC firms, nor between the DC firms and their sentries. For related work addressing matching and contract negotiation, see Ramey and Watson (1996), de Marzo and Lockwood (1998), and den Haan, Ramey, and Watson (1999).

## **VI. Implications and Suggestions for Further Research**

In this paper we studied a characteristic way in which DC buying firms build partnerships with LDC suppliers. We focused on the role that an unfamiliar environment plays in inducing the DC firms to “start small” in their relationships with LDC partners, on the persistence of these relationships in the face of opportunities for the DC firms to form new partnerships, and on the method used to motivate the effort of LDC firms. Better understanding of the decisions made by DC firms regarding cooperation with LDC firms is important because, among other things, this cooperation is a major source of technology transfer from DCs to LDCs.<sup>22</sup> Even when the DC firm is a buyer but not an equity partner (is not involved in a joint venture with the LDC firm), as is typically the case when the DC firm is a retailer rather than a manufacturer, significant

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<sup>22</sup>This is especially true when the aim of the partners is to generate exports to DC markets. Gereffi (1995) notes that LDC firms participate in exports of “branded” products to DCs in four different ways: export-processing (or in-bond) assembly, component-supply subcontracting, original equipment manufacturing, and original brand-name manufacturing. Only the last of these does not necessarily involve participation by DC firms, and is the exception rather than the rule.

technology transfer takes place.<sup>23</sup> From the point of view of these DC firms, Pack and Page (1994, pp. 220-221) note that

The motivation of the purchasers is to obtain still lower-cost, better quality products from major suppliers whose products account for a significant percentage of profits. To achieve this they are willing to transmit tacit and occasionally proprietary knowledge from their other OECD suppliers. Such transfers of knowledge are likely to characterize simpler production sectors such as clothing and footwear or more generally those older technologies that are not hedged by restrictions adopted to increase appropriability, such as patents and trade secrets.

This source of technology transfer has grown in importance in the last two to three decades as the amount of manufacturing in LDCs for markets in DCs has increased dramatically.<sup>24</sup>

Regarding technology transfer, ours is a strictly partial equilibrium model. If the matching process we describe does indeed entail considerable transfer of technological know-how from the DC firms to their LDC partners, its aggregate effect on productivity and incomes in the host country, and the feedback to search and investment decisions by the DC firms, are interesting subjects for future research.

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<sup>23</sup>Rhee, Ross-Larson, and Pursell (1984, Chapter 5) report abundant evidence for this based on their survey of Korean exporters of manufactures.

<sup>24</sup>The “developing country” share of imports of manufactured goods (SITC 5 to 8 less 68) to “developed market economies” increased from 4.8 percent in 1970 to 14.5 percent in 1991 (UNCTAD 1994, Table 3.3B, p. 94, with definitions of country groups provided in Tables 1.1 and 1.2).

## Appendix

*Proof of Proposition 1:* We saw that we can rewrite equation (1) as  $c'(r^*)[1 - (1-r^*)\delta] - \delta c(r^*) = (1-\delta)A$ . We can then totally differentiate this equation and rearrange to obtain  $dr^*/dA = (1-\delta)/c''(r^*)[1 - (1-r^*)\delta] > 0$ . The proposition then follows from the definition of  $A$ . *Q.E.D.*

*Proof of Proposition 2:* Each of  $u^B$ ,  $u^L$ , and  $u^O$  is continuous and increasing in  $w$ . Thus  $u$  is increasing and continuous in  $w$  for all values of the parameters. In addition,  $\partial u^B/\partial w = (1-p)\delta$ ,  $\partial u^L/\partial w = r^*(1-p)\delta/[1 - (1-r^*)\delta] < \delta$ , and  $\partial u^O/\partial w = \delta$ , so  $\partial u/\partial w$  is bounded above by  $\delta < 1$ .<sup>25</sup> These properties extend to the expected value of  $u$ . Thus  $Eu(\cdot; w)$  is continuous and has a slope bounded above by  $\delta < 1$ . To complete the proof we need to state conditions under which  $Eu(\cdot; 0) - \gamma > 0$ . (See Figure 2.) Note that  $u^B(\cdot; 0) = p\pi - I$ , which implies that  $u(\cdot; 0) \geq 0$ . With a distribution over  $(\pi, p, I, c)$  such that  $p\pi > I$  with positive probability, it must be that  $Eu(\cdot; 0) > 0$ . Setting  $\underline{\gamma} \equiv Eu(\cdot; 0)$ ,  $Eu(\cdot; w) - \gamma$  has exactly one fixed point if  $\gamma \leq \underline{\gamma}$  and no fixed point if  $\gamma > \underline{\gamma}$ . *Q.E.D.*

*Proof of Proposition 3:* We show in the text that, given  $w^*$ , we can find characteristics  $(\bar{\pi}, \bar{p}, \bar{I}, \bar{c})$  for which *Learn* is strictly preferred to *Big* and *Out*. Let  $\sigma'$  be the distribution that puts all mass on this partner. For all  $a \in [0, 1]$  let  $w_a^*$  be the (fixed point) value corresponding to the distribution  $\hat{\sigma}_a \equiv a\sigma' + (1-a)\sigma$  of potential partners. Consider the value of partner  $(\bar{\pi}, \bar{p}, \bar{I}, \bar{c})$  as a function of  $w$ . The properties of the cost function imply that  $r^*$  is continuous in  $w$  and it is thus

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<sup>25</sup>The expression for  $\partial u^L/\partial w$  is found using the envelope theorem.

obvious that  $u^L$ ,  $u^B$ , and  $u^O$  are continuous in  $w$ . Therefore,  $u^L(w) > u^B(w)$  and  $u^L(w) > u^O(w)$  for  $w$  sufficiently close to  $w^*$ . Similar reasoning establishes that  $w_a^*$  is continuous in  $a$  over  $[0,1]$ . These facts imply the existence of  $\bar{a}$  with the desired property. *Q.E.D.*

*Proof of Proposition 4:* We can rearrange our expression for  $u^B$  to obtain  $p\pi = u^B + I - (1-p)\delta w^*$ . This equation can be substituted into the definition for  $A$  to obtain  $A = \delta[u^B + I - (1-p)\delta w^* - pI] + (1-p)\delta w^* = \delta[u^B + (1-p)I] + (1-\delta)(1-p)\delta w^*$ . Recall that  $u^L = [r^*A - c(r^*)]/[1 - (1-r^*)\delta]$ . Since  $A' > A$ , we have  $u^{L'} > u^L$ . ( $r^{*'} may not equal  $r^*$ , but it changes to maximize  $u^{L'}$ .) *Q.E.D.*$

*Proof of Proposition 5:* Let  $w^*$  and  $\hat{w}^*$  be the (fixed point) values of selecting potential partners from the pool with search costs  $\gamma$  and  $\hat{\gamma}$ , respectively, where  $\gamma < \hat{\gamma}$ . Figure 2 shows that  $\hat{w}^* < w^*$ . Now take a potential partner with whom it is optimal to choose *Learn* under cost  $\gamma$  -- that is, a partner for whom  $u^L \geq u^B, u^O$ . We have  $\partial u^O / \partial w^* = \delta \geq \partial u^B / \partial w^* = (1-p)\delta > \partial u^L / \partial w = r^*(1-p)\delta/[1 - (1-r^*)\delta]$ , by the envelope theorem and since  $r^* < 1 - (1-r^*)\delta$  for  $r^* < 1$ . Therefore, under cost  $\hat{\gamma}$  the inequality  $u^L \geq u^B, u^O$  holds for this partner (in fact, it is strict) and *Learn* is still optimal. *Q.E.D.*

*Proof of Proposition 6:* Algebra reveals that  $B = \delta[u^B + (1-p(\alpha))(1-\delta)w + (1-p(\alpha))I(\alpha)]$ . Since  $u^B$  is constant as a function of  $\alpha$ ,  $B$  is increasing in  $\alpha$  (and thus  $u^L$  is as well). Let  $\alpha_X$  and  $\alpha_Y$  define partners  $X$  and  $Y$ , respectively. It follows that  $\alpha_X \geq \alpha_Y$ . Next note that  $v(\pi(\alpha), I(\alpha))$  is increasing in  $\alpha$ . This follows from the definition of  $u^B$ , the properties of  $\pi$  and  $I$  as functions of  $\alpha$ , and that  $u^B$  is constant in  $\alpha$ . Given a successful current partner with value  $v$ , the probability of eventually

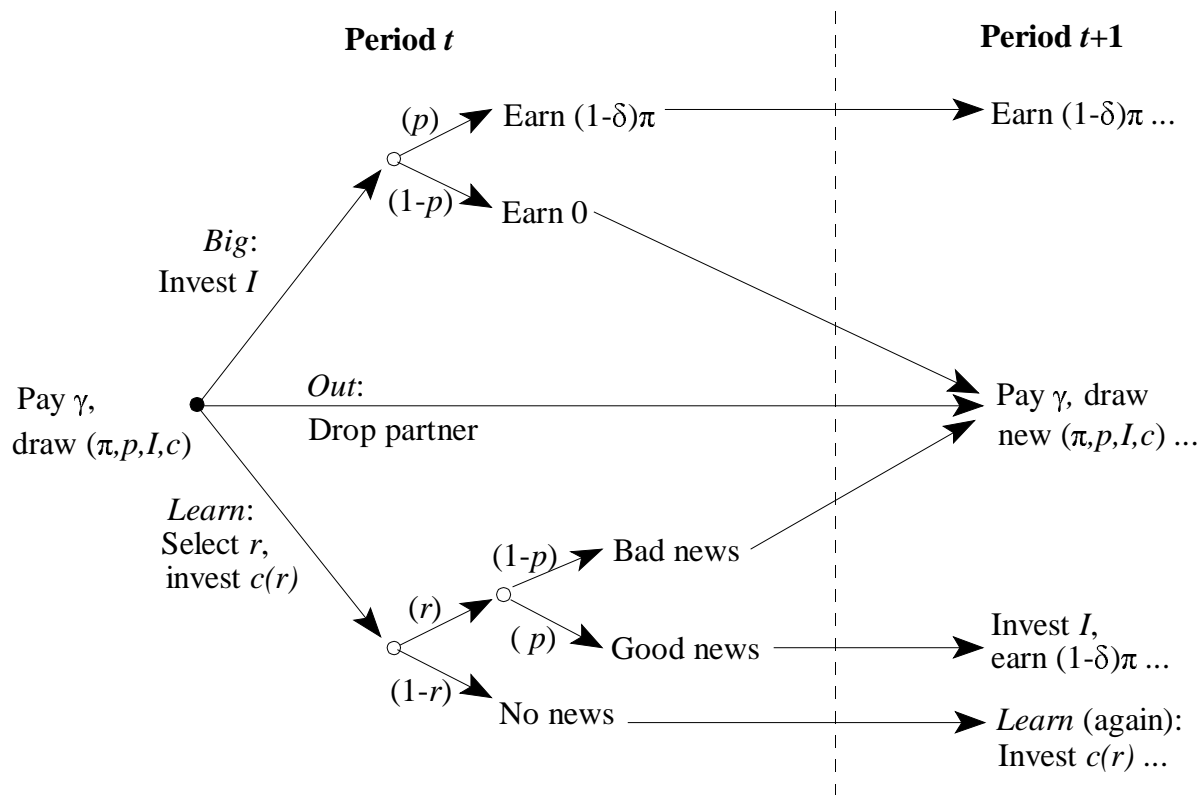


abandoning this partner in favor of a new one -- for whom information becomes available -- is obviously decreasing in  $v$ . Thus, the expected longevity of a partnership with  $X$  is weakly greater than the expected longevity of a partnership with  $Y$ . *Q.E.D.*

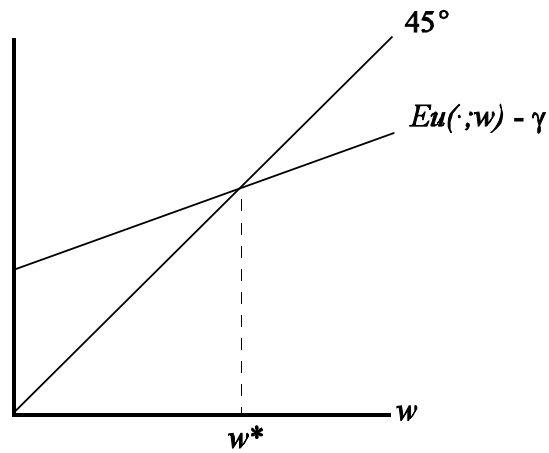
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**Figure 1**



**Figure 2**

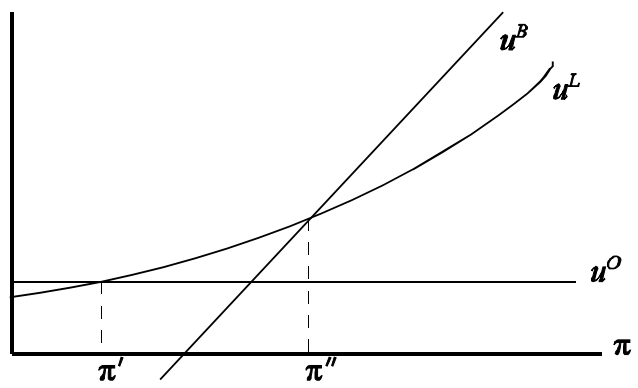


Figure 3a

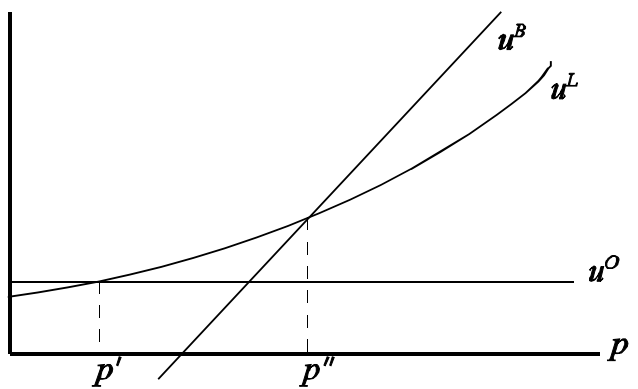


Figure 3b

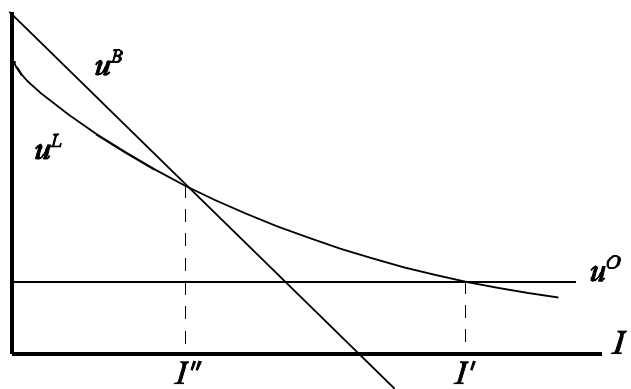


Figure 3c